# THE TIME OF GLACIAL LOESS ACCUMULATION IN ITS RELATION TO THE CLIMATIC IMPLICATIONS OF THE GREAT LOESS DEPOSITS: DID THEY CHIEFLY ACCUMULATE DURING GLACIAL RETREAT?

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Although deposits similar in several respects to glacial loess are forming today near the borders of certain deserts and along the bluffs of some great rivers, the widespread, thick loess deposits which are associated with some drift sheets imply peculiar climatic conditions, for no deserts are now close to these ancient deposits, and parts of them are far from great rivers. There have been many discussions of the probable origin of loess, and thus, indirectly, of its climatic implications. Much has been learned, among other things that different deposits accumulated under different conditions. But one question appears not to have been satisfactorily settled, that is, At what time, in respect to glaciation, did the greater part of the accumulation take place? Several American and European students have thought that the great loess deposits date from interglacial times. On the other hand, Penck has concluded that the loess was formed shortly before the commencement of the glacial epochs; while many American geologists have held that most of the loess accumulated while the ice sheets were at approximately their maximum size. Chamberlin and Salisbury,[1] McGee, and others lean toward this view.

There is evidence in support of each of these hypotheses, but it seems well to reconsider the possibilities that a large share of the great deposits associated with glaciation were formed at the one other possible glacial time, namely immediately following the retreat of the ice. Recent evidence affords light not available to the workers

[1]Chamberlin and Salisbury, *Geology*, Vol. III (1906), pp. 405–12, a comprehensive discussion of the characteristics and distribution of the American loess, with references to McGee, Shimek, and others.

years ago when the origin of the loess was under heated discussion. Furthermore, the emphasis in the past has been on the agencies of deposition rather than on the time of deposition. Indeed the latter question does not seem to have received much consideration, in spite of its importance in the interpreting of the climatic conditions during a part of the past.

These four hypotheses as to the time of origin of loess imply differences in its climatic relations. If loess was chiefly formed during typical interglacial epochs, or toward the close of such epochs, profound general aridity must seemingly have prevailed in order to kill the vegetation and thus enable the wind to pick up sufficient dust. If the loess was chiefly formed during times of extreme glaciation when the glaciers were supplying large quantities of fine material to out-flowing streams, less aridity would be required, but seemingly there must have been sharp contrasts between wet seasons in summer when the snow was melting and dry seasons in winter. Alternate floods and droughts would thus affect broad areas along the streams. Hence arises the hypothesis that the wind obtained the loess from the flood plains of streams at times of maximum glaciation. If the loess was chiefly formed during the rapid retreat of the ice, alternate summer floods and winter droughts would still prevail, but much material could also be obtained by the winds, not only from flood plains, but also from the deposits exposed by the melting of the ice and not yet covered by vegetation.

In support of the hypothesis of the interglacial origin of loess, Shimek and others state that the glacial drift which lies beneath the loess commonly gives evidence that some time elapsed between the disappearance of the ice and the deposition of the loess. For example, most of the locally abundant shells of snails in the loess are not of the sort now found in colder regions, but resemble those found in the drier regions. It is probable, Shimek concludes, that if they represented a glacial epoch all would be dwarfed by the cold as are the snails of far northern regions. The gravel pavements, discussed below, are pointed out by Shimek as strong evidence of erosion between the retreat of the ice and the deposition of the loess.

Turning to the second hypothesis, namely that the loess accumulated near the close of the interglacial epoch rather than in the

midst of it, we may follow Penck.[1] The mammalian fossils seem to him to prove that the loess was formed while boreal animals occupied the region, for they include remains of the hairy mammoth, woolly rhinoceros, and reindeer. On the other hand, the typical interglacial beds not far away yield remains of species characteristic of milder climates, such as the elephant, the smaller rhinoceros, and the deer. In connection with these facts it should be noted that occasional remains of tundra vegetation and of trees are found beneath the loess, while in the loess itself certain steppe animals, such as the common gopher, or spermaphyl, are found. Penck interprets this as indicating a progressive desiccation culminating just before the oncoming of the next ice sheet.

The evidence in favor of the hypothesis that the loess was formed during the maximum extension of the ice chiefly concerns its relation to the ice sheets and to the streams which flowed from the melting ice. If the great American deposits of loess do not represent the outwash from the Iowan ice, there is little else that does, and presumably there must have been outwash. Also the distribution of loess along the margins of streams suggests that much of the material came from the flood plains of overloaded streams flowing from the melting ice. Furthermore, in many places at least, the drift just beneath the loess presents little or no evidence of having been weathered or leached before the loess was laid down. Chamberlin found that many tests showed it to contain about as much calcareous material as the loess itself. This suggests that it was laid down at about the same time as the underlying drift, not notably afterward.[2] Likewise, although Shimek has emphasized the fact that most of the snails do not show depauperization, McGee reports that depauperization is evident among those found near the glacial margins, and that shells are very rare there. Both of these conditions suggest that much of the loess accumulated under glacial conditions.

Thus although there are some points in favor of the hypothesis that the loess originated (1) in strictly interglacial times, (2) at

[1] Penck's conclusions are given in full in W. B. Wright, *The Quarternary Ice Age*, London, 1913.

[2] T. C. Chamberlin, personal communication.

the end of the interglacial epochs, and (3) at times of full glaciation, each hypothesis is much weakened by evidence that supports the others. The evidence of boreal animals seems to disprove the hypothesis that the loess was formed in the middle of a mild interglacial epoch. On the other hand, Penck's hypothesis as to loess at the end of interglacial times fails to account for certain characteristics of the lowest part of the loess deposits and of the underlying drift. Instead of normal valleys and consequent prompt drainage, such as ought to have developed before the end of a long interglacial epoch, the surface on which the loess lies shows many undrained depressions. Some of these can be seen in exposed banks, while many more are inferred from the presence of shells of pond snails here and there in the overlying loess. The pond snails presumably lived in shallow pools occupying depressions in the uneven surface left by the ice. Another reason for questioning whether the loess was formed chiefly at the end of an interglacial epoch is that this hypothesis does not provide a reasonable origin for the material which composes the glacial loess deposits of important loess-covered regions. Near the Alps, where the loess deposits are small and where glaciers probably persisted in the interglacial epochs and thus supplied flood material in large quantities, this shortcoming perhaps does not appear important. In the broad Upper Mississippi basin, however, and also in the Black Earth region of Russia there would seem to be, during an interglacial epoch, no way to get the large body of material composing the loess, except by assuming the existence of great deserts to windward. But there is little or no evidence of such deserts where they could be effective. The mineralogical character of the loess of Iowan age proves that the material came from granitic rocks, such as formed a large part of the drift. The nearest extensive outcrops of granite are in the southwestern part of the United States, nearly a thousand miles from Iowa and Illinois. But the loess is thickest near the ice margins and thins toward the southwest and in other directions, whereas if its source was the southwestern desert its maximum thickness would probably be near the margin of the desert. Furthermore the similarity in calcareous content of the loess and the underlying drift, reported by Chamberlin, points

against Penck's hypothesis, for if the loess did not accumulate until near the close of an interglacial epoch, it is probable that the calcareous matter would have been largely leached from the upper layers of the underlying drift. The interglacial epochs are now known to have been sufficiently long for much weathering to take place. Thus considerable evidence seems inconsistent with the hypothesis that the loess was formed chiefly toward the close of an interglacial epoch.

There is much less evidence against the hypothesis that the great loess deposits accumulated chiefly during the maximum extension of the ice. Indeed it remains as a worthy working hypothesis. However, the question may be raised as to whether or not flood plains of streams would provide adequate supplies of materials for such widespread, rather uniform deposits as those of Russia and of Iowa and Illinois. A further question comes to mind: Would the type of vegetation which would probably occur along the ice front at its maximum extension be that of which the loess gives evidence? Indeed it seems probable that when the ice advanced, its front lay close to areas where the vegetation was not much thinner than that which today prevails under similar climatic conditions. If the average temperature of glacial maxima was only about 6°C. lower than that of today, as many authorities consider likely, the conditions just beyond the ice front when it was in the loess region from southern Indiana to Nebraska would probably have been like those now prevailing in Canada from New Brunswick to Winnipeg. The vegetation there is quite different from the grassy vegetation of which evidence is found in the loess. The roots and stalks of such grassy vegetation are generally agreed to have helped produce the columnar structure which enables the loess to stand with almost vertical surface. Thus it seems appropriate to add a supplementary hypothesis to suggest that certain phenomena would be readily explainable in case the chief accumulation was during glacial retreat, rather than at the time of maximum extension of ice.

We are now ready to consider the probability that loess accumulated mainly during the retreat of the ice. Such a retreat exposed a zone of drift to the out-blowing glacial winds. Most glacial hypotheses, such as that of uplift, or depleted carbon dioxide,

call for a gradual retreat of the ice scarcely faster than the vegetation could advance into the abandoned area. Under Huntington's solar-cyclonic hypothesis,[1] on the other hand, the climatic changes may have been sudden and hence the retreat of the ice may have been much more rapid than the advance of vegetation. Now wind-blown materials are derived from places where vegetation is scanty. Scanty vegetation on good soil, it is true, is usually due to aridity, but may also result because the time since the soil was exposed has not been long enough so that it may be covered with vegetation. Sand bars, mud flats, and flood plains are common examples. Moreover, violent winds and low temperatures may prevent the spread of vegetation. Thus it appears that unless the retreat of the ice were as slow as the advance of vegetation, a barren area of more or less width must have bordered the retreating ice and formed an ideal source of loess.

Several other lines of evidence seemingly support the conclusion that the loess was chiefly formed during the retreat of the ice. For example, Shimek, who has made almost a life-long study of the Iowan loess, emphasizes the fact that there is often an accumulation of stones and pebbles at its base. This suggests that the underlying till was eroded before the loess was deposited upon it. The first reaction of most students is to assume that of course this was due to running water. That is possible in many cases, but by no means in all. So widespread a sheet of gravel could not be deposited by streams without destroying the irregular basins and hollows of which we have seen evidence where the loess lies on glacial deposits. On the other hand, the wind is competent to produce a similar gravel pavement without destroying the old topography. "Desert pavements" are a notable feature in most deserts. The commonest winds are outward near the edge of an ice sheet, as Hobbs has made us realize.[2] They often attain a velocity of eighty miles an hour in Antarctica and Greenland.

[1] Ellsworth Huntington, *Earth and Sun*, Yale Press, New Haven, 1922; and Huntington and Visher, *Climatic Changes, Their Nature and Causes*, Yale Press, 1922.

[2] W. H. Hobbs, *Characteristics of Existing Glaciers*, 1911; "The Rôle of the Glacial Anti-Cyclone in the Air Circulation of the Globe," *Proceed. Am. Phil. Soc.*, Vol. LIV (1915), pp. 185–225.

Such winds, however, usually decline rapidly in velocity only a few score miles from the ice. Thus their effect would be to produce rapid erosion of the freshly bared surface near the retreating ice. The pebbles would be left behind as a pavement, while sand and then loess would be deposited farther from the ice where the winds were weaker and where vegetation was beginning to take root. Such a decrease in wind velocity may explain the occasional vertical gradation from gravel through sand to coarse loess and then to normal fine loess. As the ice sheet retreated, the wind in any given place would gradually become less violent. As the ice continued to retreat, the area where loess was deposited would follow at a distance, and thus each part of the gravel pavement would in turn be covered with loess.

The hypothesis that loess is deposited while the ice is retreating is in accord with many other lines of evidence. For example, it accords with the boreal character of the mammal remains as described above and of the depauperated snail fauna found in the zone nearest the ancient ice sheets. Again, the advance of vegetation into the barren zone along the front of the ice would be delayed by the strong out-blowing winds. The common pioneer plants depend largely on the wind for the distribution of their seeds, but the glacial winds would carry them away from the ice rather than toward it. The glacial winds discourage the advance of vegetation in another way, for they are drying winds, as are almost all winds blowing from a colder to a warmer region. Such winds, however, would interfere less with the northward spread of grasses propagated by root shoots and by abundant seeds than it would interfere with the spread of trees. The fact that remains of trees sometimes occur at the bottom of the loess probably means that the deposition of loess extended into the forests which almost certainly persisted not far from the ice at its maximum advance. This seems more likely than that a period of severe aridity before the coming of the glacier killed the trees and made a widespread steppe or desert. Penck's chief argument in favor of the formation of loess before the advance of the ice rather than after appears to be that since loess is lacking upon the youngest drift sheet in Europe it must have been formed before rather than after the last or Würm advance of

the ice. This argument is not convincing for two special reasons: First, on the corresponding (Wisconsin) drift sheet in America loess is present—in small quantities to be sure, but unmistakably present. Second, there is no reason to assume that conditions were identical at each advance and retreat of the ice. Indeed, the fact that in Europe, as in the United States, nearly all the loess was formed at one time, and only a little is associated with the other ice advances, points clearly against Penck's fundamental assumption that the accumulation of loess was due to the approach of a cold climate. The relative abundance of loess associated with the Iowan ice sheet would be explained by the present hypothesis if ice retreated more rapidly for a time than did any of the later ice sheets.

Thus the hypothesis that the loess accumulated chiefly during the retreat of the ice sheets appears to have enough support to merit consideration by students of loess.